# BATTLE INJURIES OF THE ARTERIES IN WORLD WAR II*

## AN ANALYSIS OF 2,471 CASES

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ACUTE INJURIES OF MAJOR ARTERIES, which literally threaten both life and limb, have always constituted a serious problem in the surgical management of traumatic conditions. In times of war, this subject assumes even greater significance, and further impetus is, therefore, provided for the study of the problem and the development of a more effective solution. Although considerable progress was made in this field of surgical endeavor in the interval between World War I and World War II, early experience in the latter conflict soon showed that satisfactory methods of managing arterial injuries were yet to be developed. Moreover, there was little unanimity of opinon concerning either concepts of management or procedures of choice in individual cases. As experience increased and as various technics were tested, increasing difficulty was met in their evaluation because there were no accurate figures on survival expectancy after acute ligation of arteries under war-time conditions. For these reasons, special efforts were made in certain active Theaters of War to study the problem intensively and to collect data which would permit analysis and would provide more definitive information concerning it.

In this report an effort has been made to present as accurately as possible, on the basis of data now at hand, information as to war wounds of the arteries occurring in American Forces during World War II, with respect to incidence, types, location, morbidity, methods of management, and factors influencing the outcome. These data have been obtained from all sources available to the Surgeon General's Office, including special reports from consultants, hospitals and field units, as well as from individual medical officers who have made special studies of arterial wounds. Comparisons of significant data, methods and concepts have been made with those of previous wars whenever it seemed pertinent or desirable.

It should be clearly understood that the data derived from the 2,471 arterial wounds on which this analysis is based pertain only to fresh or acute wounds and not to later and more chronic types of complications, such as traumatic false aneurysm (including the so-called pulsating hematoma) and arteriovenous aneurysm. It is most important to bear this in mind, for much confusion has arisen in the past from failure to define clearly the type and character of the data reported and from the inclusion of acute and chronic lesions in the same reported series.

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## INCIDENCE

A search of the literature reveals little information concerning the incidence of wounds of the arteries among battle casualties in previous wars. Generally, the statistics which are available would seem to underestimate the incidence of this type of wound. Even in World War II, when a real effort was made to report the figures accurately, the data are still deficient in certain respects. The lack of information is not difficult to explain: For obvious reasons vascular injury is seldom recorded as a primary diagnosis, and in many instances, including both the most serious and the least serious cases, it is probably not
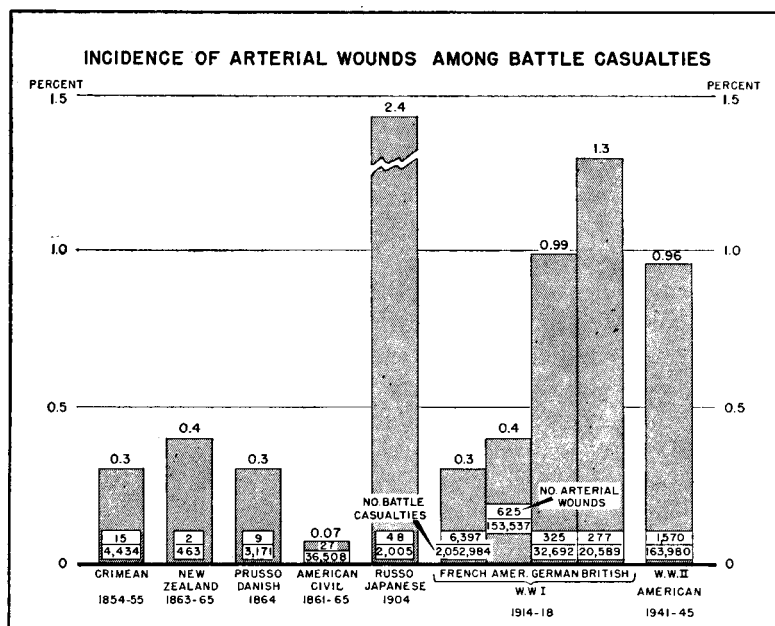


CHART 1.—Incidence of arterial wounds among battle casualties in various wars.

recorded at all. In addition, analysis of the available statistics requires considerable caution. Most series are actually or relatively small, and many from previous wars include both acute and nonacute conditions. In drawing conclusions from them, therefore, many qualifying circumstances must be taken into account.

All available statistics (Chart 1) suggest that the incidence of arterial wounds among battle casualties in previous wars was extremely low, ranging from 0.07 per cent in the War Between the States to 2.4 per cent in the Russo-Japanese War.[24, 63, 119, 120, 122, 143, 162] LaGarde reported an incidence of 0.8 per cent in 1,400 casualties at Santiago during the Spanish-American War.

From data tabulated in the official American history of World War I the incidence of vascular wounds among American troops has been computed to be 0.4 per cent (Chart 1).[120] The British official history,[129] although it devotes considerable space to the subject of arterial wounds, supplies no data concern-

ing incidence, and Makins' classic monograph[128] on gunshot injuries of the blood vessels says nothing on this point. His material, as a matter of fact, is limited to 1,191 cases (Table I) made up of two series; one consists of 668 cases handled by numerous individual surgeons in the British Isles and over-

TABLE I

| | BRITISH WORLD WAR I (MAKINA*) | | | | AMERICAN WORLD WAR II | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Loss of Limb† | | | | Loss of Limb | |
| | Total No. | % Total | No. Cases | Per Cent | Total No. | % Total | No. Cases | Per Cent |
| Aorta............ | 5 | 0.4 | 5 | 100.0 | 3 | 0.12 | 2 | 66.6 |
| Carotid.......... | 128 | 10.7 | 38 | 29.6 | 10 | 0.4 | 3 | 30.0 |
| External carotid.... | | | | | 3 | 0.12 | 0 | 00.0 |
| Renal............ | | | | | 2 | 0.10 | 2 | 100.0 |
| Vertebral......... | 3 | 0.2 | 0 | | | | | |
| Subclavian........ | 45 | 3.7 | 4 | 8.8 | 21 | 0.85 | 6 | 28.6 |
| Axillary.......... | 108 | 9.0 | 5 | 4.6 | 74 | 0.30 | 32 | 43.2 |
| Brachial total...... | 200 | 16.7 | 12 | 6.0 | 601 | 24.3 | 159 | 26.5 |
| Above profunda.. | | | | | 97 | 3.9 | 54 | 55.7 |
| Below profunda.. | | | | | 209 | 8.5 | 54 | 25.8 |
| Radial-ulnar....... | 59 | 4.9 | 3 | 5.0 | | | | |
| Radial......... | | | | | 99 | 4.0 | 5 | 5.1 |
| Ulnar.......... | | | | | 69 | 2.8 | 1 | 1.5 |
| Radial and ulnar... | | | | | 28 | 1.1 | 11 | 39.3 |
| Common iliac...... | 1 | 0.1 | 1 | 100.0 | 13 | 0.5 | 7 | 53.8 |
| External iliac...... | 4 | 0.3 | 0 | 0 | 30 | 1.2 | 14 | 46.7 |
| Internal iliac....... | 1 | 0.1 | | | 1 | 0.05 | 0 | 00.0 |
| Femoral total...... | 366 | 30.5 | 74 | 20.2 | 517 | 20.9 | 275 | 53.2 |
| Above profunda.. | | | | | 106 | 4.3 | 86 | 81.1 |
| Below profunda.. | | | | | 177 | 7.2 | 97 | 54.8 |
| Profunda........ | | | | | 27 | 1.1 | 0 | 00.0 |
| Popliteal.......... | 144 | 12.0 | 62 | 43.1 | 502 | 20.3 | 364 | 72.5 |
| Anterial tibial...... | 26 | 2.2 | 1 | 3.8 | 129 | 5.2 | 11 | 8.5 |
| Posterior tibial..... | 97 | 8.1 | 9 | 9.2 | 265 | 10.7 | 36 | 13.6 |
| Ant. and post. tibial | 7 | 0.6 | 2 | 28.6 | 91 | 3.7 | 63 | 69.2 |
| Peroneal.......... | 4 | 0.3 | 2 | 50.0 | 7 | 0.28 | 1 | 14.3 |
| Ant. tibial and peroneal........ | 3 | 0.2 | 0 | 0 | | | | |
| Post. tibial and peroneal........ | 1 | 0.1 | 0 | 0 | 5 | 0.20 | 2 | 40.0 |
| Both tibials and peroneals........ | | | | | 1 | 0.05 | 1 | 100.0 |
| Total........ | 1202‡ | | 218 | 18.1 | 2471 | | 995 | 40.3 |

* The figures compiled from Makins' tables represent combinations of the totals for "gangrene" and "amputations," so that the maximum number was obtained without possible duplications. The numbers represent the minimum number of cases that must have had amputations.

† In case of aorta, carotids, and renal arteries, the figures indicate the numbers that died or developed cerebral complications.

‡ This total differs from the number of 1,191 cases given in Makins' master table, because 11 vessels of the leg were added from a detailed table presented in the text.

seas, and the other of 523 cases similarly handled in France but supervised by a single surgeon. Only modified reliance, Makins warned, could be placed on any deductions drawn from this material, and it contributes nothing to the incidence of vascular wounds among British troops in World War I. The only material available on that subject was found in Bowlby and Wallace's report of 20,589 casualties treated at a single casualty clearing station, 277 of whom (1.3 per cent) required ligation of major arteries.

Maurer[135] recorded 443 wounds of the blood vessels observed among 8,000 wounded treated in a French ambulance service. If the 17 per cent of wounds involving only the veins be excluded, the incidence of arterial injuries is 4.6 per cent. Figures reported by Mignon (so stated that a tabulation was possible) for six French ambulances show 399 vascular injuries (2.02 per cent) among 19,734 wounded. The French official history of World War I[148] shows 6,397 vascular injuries (0.99 per cent) among 2,052,984 wounded. The German incidence, according to Franz, was 0.99 per cent.

Matas,[132] in his exhaustive consideration of vascular injuries, stated that in World War I, 24.7 per cent of battle casualties at the front required treatment for injuries of the blood vessels and added that 2 per cent of all wounded admitted to Base Hospitals presented traumatic aneurysms. These are the highest figures that have been found in the literature for the incidence of vascular injuries among battle casualties, and the source material upon which they were based was not indicated.

TABLE II

CAUSES OF AMPUTATION IN 189 CASES OF VASCULAR INJURY*

|  | 1943 | | 1944–45 | | 1943–45 | |
| --- | --- | --- | --- | --- | --- | --- |
|  | Cases | Per Cent | Cases | Per Cent | Cases | Per Cent |
| Primary ............... |  |  | 43 | 32.3 | 43 | 22.8 |
| Gangrene............... | 47 | 84.0 | 64 | 48.1 | 111 | 58.7 |
| Clostridial myositis....... | 8 | 14.0 | 13 | 9.8 | 21 | 11.1 |
| Other infections.......... | 1 | 2.0 | 13 | 9.8 | 14 | 7.4 |
| Total............... | 56 | 100.0 | 133 | 100.0 | 189 | 100.0 |

* Amputations done at initial wound surgery, when vascular injury made survival of limb unlikely.

*World War II.*—Considerably more data on which to base estimates of the incidence of vascular injuries among battle casualties are available for World War II. Moore stated that the 13 vascular injuries which he treated in a German prison camp formed 0.43 per cent of all hospital admissions. All the patients were seen late (between three and 42 days after wounding) and the circumstances necessarily made the group highly selective. Cole and Neel found nine injuries of major vessels (1.4 per cent) among 638 wounds of the extremities sustained in amphibious warfare in the Pacific.

At the present writing, reasonably complete data are available from armies in three of the most active American Theaters of Operation in different parts of the world. The total incidence of 0.96 per cent (1,570 vascular injuries among 163,980 battle casualties) is remarkably close to the incidences reported from the separate Theaters and armies (Chart 2). The similar correspondence noted in the distribution of vascular wounds among wounds of the extremities observed in the separate Theaters and armies suggests that the over-all incidence of 1.4 per cent is fairly representative (Chart 3).

*Incidence in Relation to Amputation.*—The total incidence of vascular wounds among all casualties, and even among wounds of the extremities, is both relatively and absolutely small, and even the large numbers of wounded in World War II do not make the total number of vascular wounds very large.
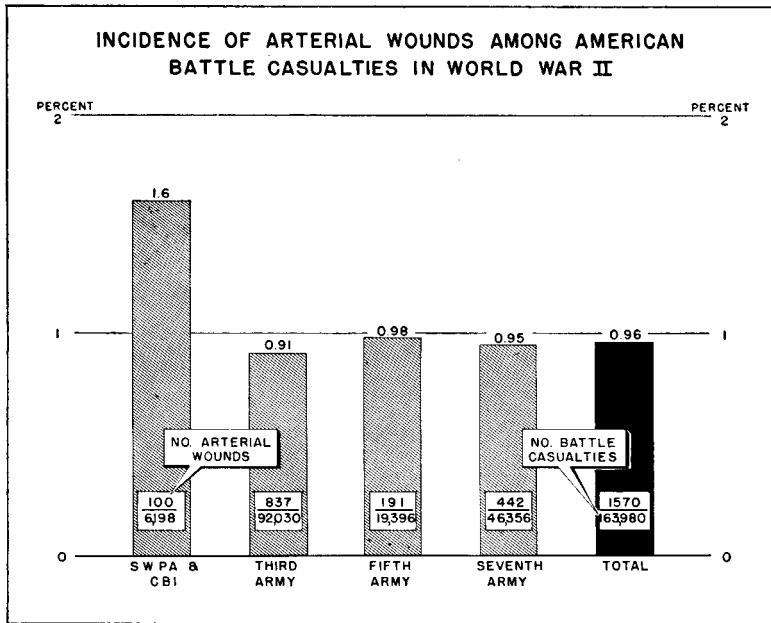
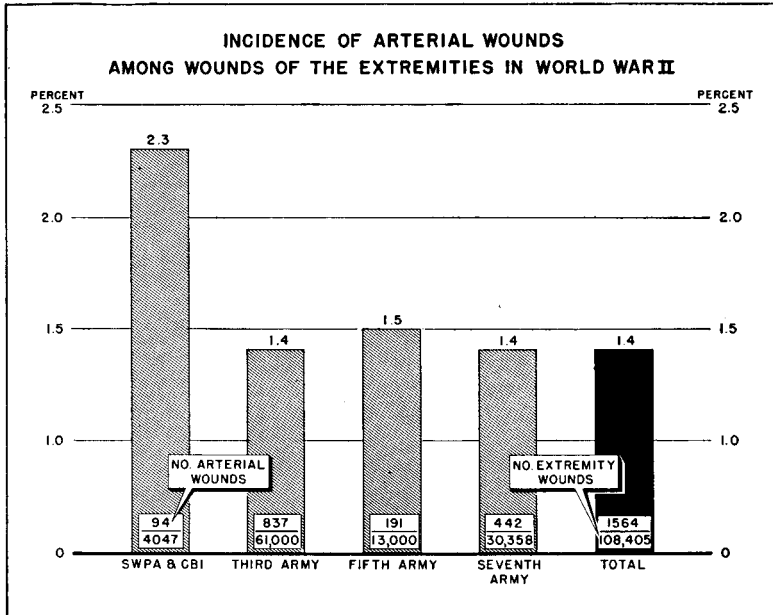CHART 2.—Incidence of arterial wounds among American battle casualties in World War II.



CHART 3.—Incidence of arterial wounds among wounds of the extremities in American battle casualties in World War II.

The real significance of these injuries, however, is better appreciated by examining the frequency with which they appear as a cause for amputation.

No significant statistics compiled from this point of view have been found in the literature, but accurate data are available from the Mediterranean and European Theaters of Operation (Chart 4). Among 3,177 major amputations from these Theaters, 2,179 (68.6 per cent) were the result of extensive trauma, 380 (11.9 per cent) were the result of clostridial myositis or other serious infections, and 618 (19.5 per cent) were the result of major arterial injuries. Figures which became available with the capture of a German amputation Center showed that among 1,359 major amputations, 64.3 per cent were the
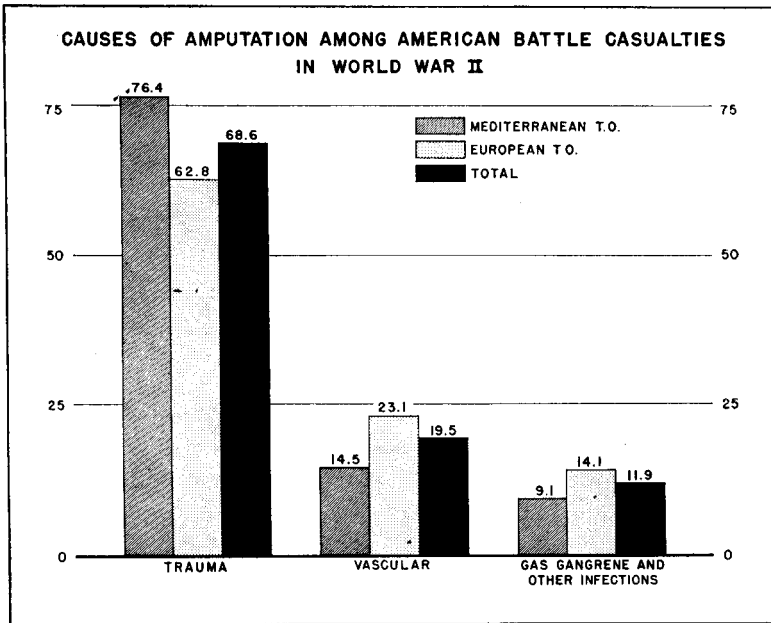


CHART 4.—Causes of amputation among American battle casualties in World War II.

result of trauma, which is close to the American incidence of 68.6 per cent. Only 6 per cent, however, were the result of vascular injuries, while 29.7 per cent were the result of clostridial myositis. Corresponding figures on the Russian experience have been reported by Kramarov, who observed that trauma was the cause for amputation in 16 per cent of the cases, vascular injury in 5 per cent, and gas gangrene and other infections in 79 per cent. The far smaller incidence of the latter in the American statistics is a reflection of the highly creditable standards of surgery achieved by American surgeons in Forward Areas.

The figures which have been presented in this section provide a much better perspective of the vascular problem in war surgery than has previously been possible. For one thing, they provide a true concept of the magnitude of the

problem. For another, they make clear that the great majority of amputations are inevitable and beyond the surgeon's control. Therapeutic measures designed to save the limb are clearly applicable, at best, to not more than 20 to 25 per cent of all such injuries, which should put to rest the overenthusiastic and even extravagant claims occasionally made as to the possibilities of salvage of limbs in battle wounds of the blood vessels.

*Regional Distribution of Vascular Injuries.*—An analysis of the relative frequency with which various arteries are involved in battle casualties (Chart 5, Table I) shows that the brachial, tibial, femoral and popliteal arteries are involved far more frequently than any others. They accounted for 70 per cent of the total vascular injuries reported by Makins and for 85 per cent of the vascular injuries sustained by American troops in certain Theaters of Oper-
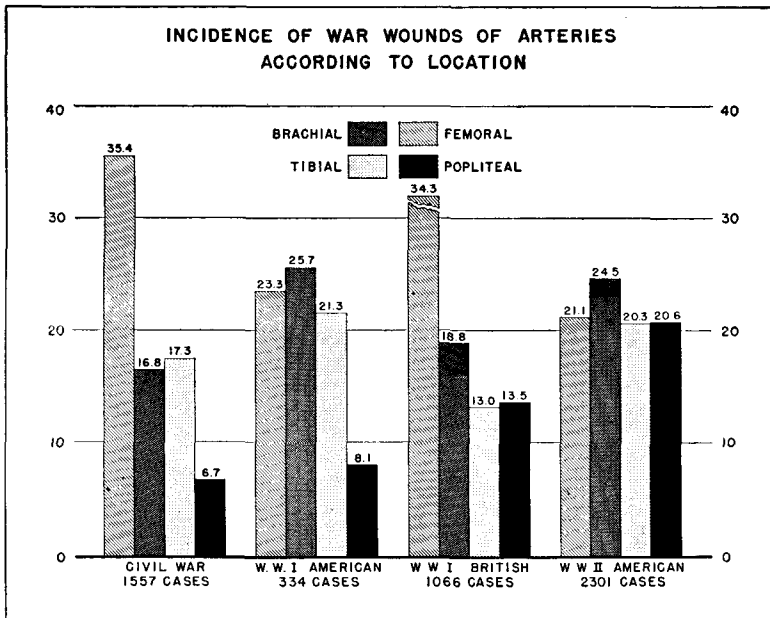


CHART 5.—Distribution according to site of arterial wounds of the extremities in various wars. These incidences, it should be emphasized, are based only on arterial wounds of the extremities, whereas those shown in Table I are based upon all arterial wounds.

ation in World War II. The explanation of this preponderance is simple: Casualties suffering from injuries of larger arteries frequently do not live long enough to reach medical installations (and, therefore, do not appear under precise diagnoses in medical statistics), while injuries of less critical arteries are frequently not discovered at all, or, if discovered, are not recorded.

A comparison of the incidences of wounds of the brachial, tibial, femoral and popliteal arteries in the War Between the States, World War I (British and American statistics) and World War II (American statistics) shows a relatively close order of magnitude of the incidences of wounds of these four

arteries in World War II as compared with earlier wars, and a much higher incidence of popliteal injuries in the recently terminated war as compared with previous wars. The explanation for these differences can be only conjectural. It may lie in more exact methods of recording, in a greater and more selective interest in vascular injuries, and perhaps in the more conservative surgical policies directed toward conservation of limbs in World War II.

### THE THERAPY OF VASCULAR INJURIES
### GENERAL CONSIDERATIONS

Any discussion of the therapy of vascular injuries must begin with the premise that the restoration of the flow of blood through the original channel is the desideratum. Unfortunately, even in civilian traumatic surgery, this can be accomplished in only a limited number of cases, while in military surgery

EFFECT OF TIME-LAG BETWEEN WOUNDING AND OPERATION
ON INCIDENCE OF AMPUTATION IN ARTERIAL WOUNDS

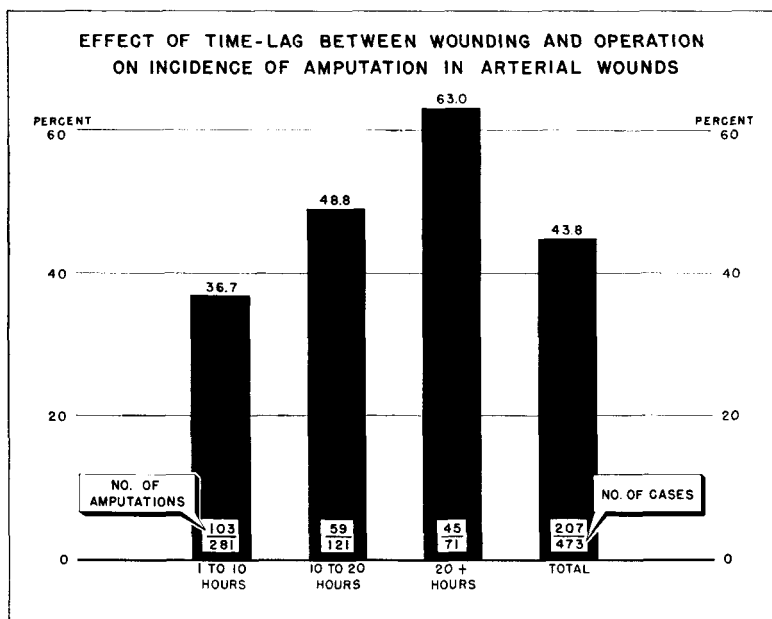| | 1 TO 10 HOURS | 10 TO 20 HOURS | 20 + HOURS | TOTAL |
|---|---|---|---|---|
| PERCENT | 36.7 | 48.8 | 63.0 | 43.8 |
| NO. OF AMPUTATIONS | 103 | 59 | 45 | 207 |
| NO. OF CASES | 281 | 121 | 71 | 473 |

CHART 6.—Effect of time-lag between wounding and operation on incidence of amputation in arterial wounds of the extremities among American battle casualties in World War II.

the number is even more limited for certain definite reasons enumerated below. Essentially, these reasons may be divided into two categories: (1) Those in which the factors are of such vital significance that they seal the fate of the limb regardless of any form of therapy; and (2) those which jeopardize the effects of ideal therapy or preclude its institution.

*Time-Lag.*—Ideal therapy, designed to reestablish the circulation of the limb, must be done within a limited period of time after wounding. The general (arbitrarily set) limit is six to eight hours. The time-lag in military surgery, however, is predominantly a military matter. Even under the happiest

circumstances the time-lapse between wounding and treatment in the majority
of injuries averages over 12 hours.* After such a lapse of time, regardless of
the nature of the original wound, thrombosis has probably occurred in the
vascular tree distal to the injury and the tissues of the wounded extremity have
been deprived of oxygen and nutrition too long a time for the changes to be
reversible.

In the material from the American armies studied from this point of view,
only a negligible number of patients were seen much earlier than ten hours
after wounding, which explains why the results in the one-to-ten-hour category
are not very much better than for the group as a whole (Chart 6). Infection is
probably not an important factor in this category, though it plays an increas-
ingly important rôle after the ten-hour period and undoubtedly accounts for
at least a portion of the unhappy results in the group observed 20 hours or
more after wounding. On the other hand, from the standpoint of possible rees-
tablishment of the circulation, it is questionable whether a time-lag of more
than ten hours is of special significance, since, as already pointed out, pro-
cedures designed for this purpose must be instituted within the upper limits of
this period if good results are to be anticipated.

From the military standpoint, it is doubtful that the time-lag can be greatly
reduced. Nearly half of it* is taken up by the period between wounding and
the administration of first aid. In World War II every effort was made to
bring surgical care as near the front lines as possible, so as to cut down the
time-lag, but it is highly unlikely that it could be instituted at the Battalion Aid
Station level, or that it should be. The best that can be done is not always the
best thing to do.

The establishment of vascular wounds as a special category, to be handled
by a special routine, also does not seem practical.[156] For one thing, for such a
classification to operate effectively would require of medical corpsmen a degree
of differential diagnostic skill which they could not be expected to possess. For
another, vascular injuries constitute such a small proportion of the total
wounded that the imposition of another special category on the already over-
burdened military organization would seem scarcely justified.

Methods to preserve the circulation until patients with vascular injuries
reach installations at which specialized surgery can be done are simply not
practical. Supplemental sympathectomy, for instance, would be done with
much greater difficulty in a Field Hospital than in a civilian hospital, and
sympathetic block is open to the same criticism. The use of heparin before
the patient reaches a hospital installation with laboratory facilities would be
most unsafe, in view of the precautions necessary when any variety of anti-
coagulant therapy is employed, and might have disastrous consequences.

* In a group of 104 "first priority" patients studied in the Mediterranean Theater,
the time-lapse from wounding to arrival at the first hospital installation (Field Hospital)
varied between one and 34.5 hours and averaged 12.5 hours. The average time-lag between
wounding and tagging (first aid) varied between a few minutes and 25 hours, and aver-
aged five hours. The time-lag from arrival in the hospital to operation varied between
one and 10.75 hours and averaged 3.75 hours. In a sample of 58 cases with vascular
injuries, the time-lag between wounding and surgical treatment averaged 15.2 hours.

*Practical Difficulties.*—Ideal vascular surgery is difficult surgery. It requires special equipment, a great deal of time, and, on the part of the surgeon, highly specialized experience and dexterity.[49] The exigencies of the military situation are such that patients are not invariably seen by specialized personnel in the most Forward Installations. In Battalion Aid Stations they are observed by nonspecialized medical personnel, and occasionally only by military administrative officers; neither group is fitted or equipped to institute specialized treatment. Furthermore, even when they reach installations at which definitive surgery can be done, the ablest surgeons cannot produce
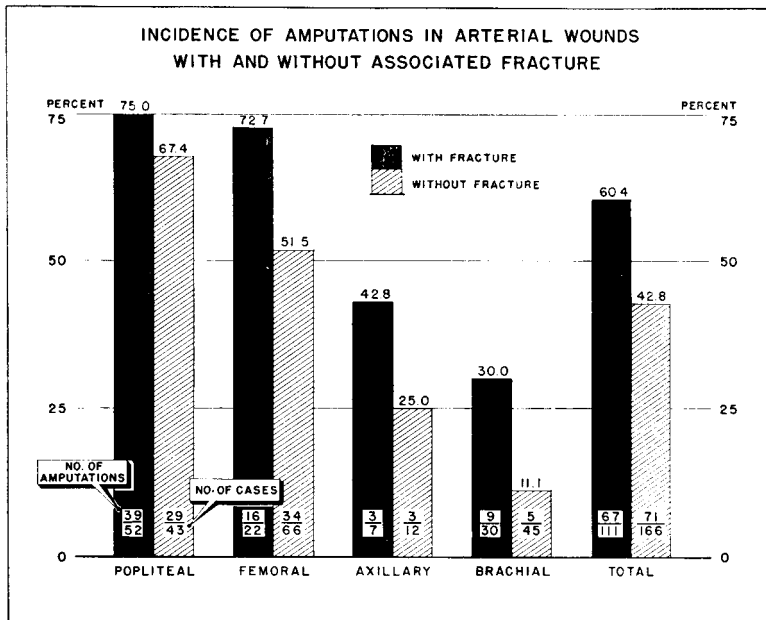


CHART 7.—Effect of presence or absence of associated fractures on incidence of amputation in arterial wounds of the extremities among American battle casualties in World War II.

outstanding results when they are working against factors beyond their control which, as will be pointed out, determine, far more than what they do, the outcome in any given series of cases.

*Associated Injuries.*—Vascular wounds, like all other battle wounds, occur singly in not more than two-thirds of the cases. They may be associated with other local wounds, which further impair or perhaps completely destroy the regional circulation. They may be associated with more remote wounds, some of which may require attention far more urgently, as a life-saving matter, than does the vascular wound; ideal vascular therapy must frequently be deferred for such a reason. Moreover, even if the vascular wound is single, the patient may be in such poor condition from exposure, loss of blood, or other causes that ideal vascular surgery must be postponed until he is in condition to withstand it. In other words, important as is the salvage of a limb, the salvage of life necessarily takes precedence of it.

To determine the possible effect of associated injuries, the presence or absence of fractures was studied, in relation to the outcome, in the material from the American armies (Chart 7). The incidence of amputation was significantly higher in the group in which vascular injuries were complicated by fractures, which suggests, in addition to the absolute significance of the observation, the importance of knowing all the circumstances about series of cases before drawing conclusions from comparative studies.

## INCIDENCE OF AMPUTATION FOLLOWING WOUNDS OF THE ARTERIES OF THE EXTREMITIES

| Site | Percent Amputations |
|------|---------------------|
| TOTAL CASES | 18.1 / 40.3 |
| BRACHIAL (TOTAL) | 6.0 / 26.1 |
| SUBCLAVIAN | 8.8 / 28.6 |
| RADIAL AND ULNAR | 39.3 |
| AXILLARY | 4.6 / 43.2 |
| EXTERNAL ILIAC | 46.7 |
| COMMON ILIAC | 53.8 |
| FEMORAL (TOTAL) | 20.2 / 53.2 |
| ANTERIOR & POSTERIOR TIBIALS | 28.6 / 69.2 |
| POPLITEAL | 43.1 / 72.5 |

AMERICAN W W II EXPERIENCE

BRITISH W.W. I EXPERIENCE
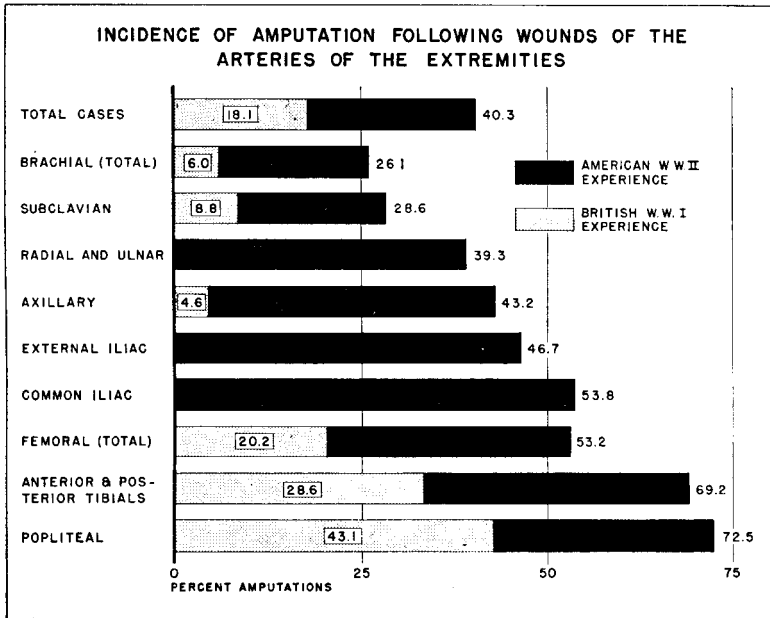
0    25    50    75
PERCENT AMPUTATIONS

CHART 8.—Effect of site of arterial wounds of the extremities on incidence of amputation in American battle casualties in World War II and in British battle casualties in World War I.

Another consideration which might be mentioned at this time is the amount of blood the patient has lost. In the majority of vascular wounds there has usually been a considerable loss before first aid can be instituted. In a sample group of 27 patients studied a week after wounding, the red blood cell count still averaged only 2,700,000 per cu. mm., and the hemoglobin concentration in 24 of the cases was still only 60 per cent of normal, despite the fact that these patients had received whole blood in amounts that had been thought adequate. One of these patients, with a wound of the femoral artery, had lost 40 per cent of the normal blood volume when he was first seen.

Naturally, if the volume of the circulating blood is reduced, the amount of blood which passes through the peripheral arteries is also reduced, the circulation of the distal portion of the extremity with a vascular injury is still further reduced, and its nutrition suffers correspondingly. From both the systemic and the local standpoints a most important consideration in the therapy of vascular wounds is the prompt restoration of the circulating blood volume

and the hemoglobin concentration. The point deserves to be emphasized, for it is frequently forgotten that the patient with a wound of the extremity often requires an equal or even greater quantity of blood than a patient with a wound of the chest or the abdomen.

*Site of Wound.*—On the basis of actual experience and under the conditions or limitations imposed by military practice, the categoric statement can be made that the site and type of the vascular wound determine the therapeutic procedure and, therefore, predetermine, so to speak, the end-results. The American experience in World War II, as well as the British experience in World War I when detailed statistics were available for analysis (Chart 8), make clear that wounds of certain vessels, such as the popliteal artery, are much more likely to be followed by ischemic gangrene than are wounds of certain other vessels, such as the brachial artery. Indeed, for practical purposes it is possible to make up categories of critical and noncritical arteries. On the other hand, while a wound of either the anterior or the posterior tibial artery alone was relatively noncritical in the material studied, wounds involving both arteries resulted in the second highest proportion of gangrene in both the British and the American material. Generally speaking, lesions in the lower extremity are more serious than lesions in the upper extremity (Chart 9). A comparison of the incidence of amputations following wounds of the major arteries of the upper extremities (from the subclavian through the brachial) with those of the lower extremity (from the iliac through the popliteal) makes this clear. Furthermore, where the brachial and femoral arteries are concerned, whether the injury is above or below the profunda branch (Chart 10) plays an important rôle in the incidence of amputation. If the cases in which only single vessels of the forearm and leg (radial, ulnar, anterior and posterial tibial, and peroneal arteries) are excluded from the 2,453 arterial wounds of the extremities collected from American armies in various Theaters of Operation (Table I), the incidence of amputation after vascular injury rises to 49.6 per cent. If only wounds of the iliac, femoral and popliteal arteries and multiple arterial wounds of the leg are considered, it rises to 62.6 per cent (Table I). The British figures for World War I are similarly striking (Table I).

As these various figures show, in any unselected group of vascular injuries the proportion of poor results will be high or low, according to the number of important or unimportant vessels involved. The surgeon has no factor of choice, and, therefore, no responsibility, in this respect. The site of the wound is not of his selection, but he must necessarily institute therapy in reference to its location.

*Type of Arterial Lesion.*—The type, which to some extent is concerned with the size, of the arterial wound, has a two-fold importance: its effect upon the adequacy of the circulation in the distal portion of the wounded extremity, and its influence upon the type of surgical procedure possible. Generally speaking, the larger the injury, (1) the greater the chance that the collateral circulation will be damaged; (2) the more extensive the necessary débridement; and (3) the greater the chance of infection if débridement is not adequate.
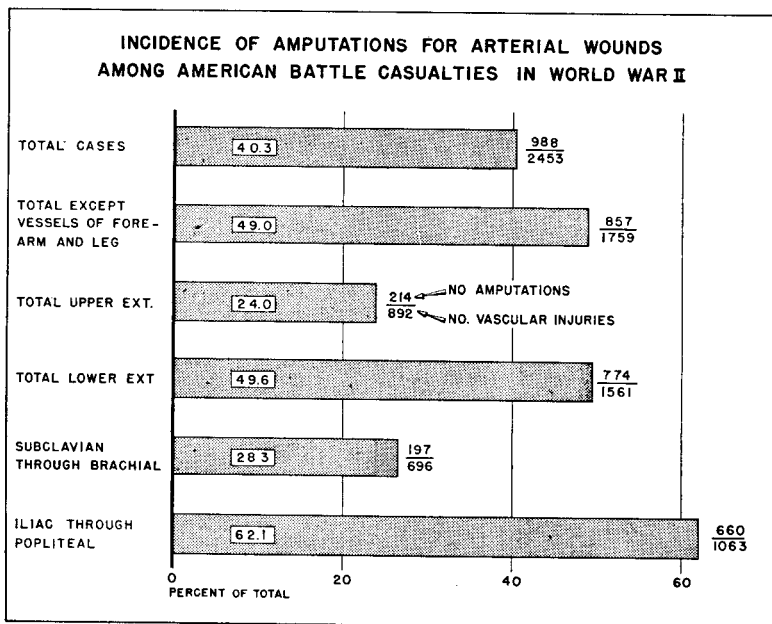
INCIDENCE OF AMPUTATIONS FOR ARTERIAL WOUNDS
AMONG AMERICAN BATTLE CASUALTIES IN WORLD WAR II

TOTAL CASES — 40.3 — $\frac{988}{2453}$

TOTAL EXCEPT VESSELS OF FORE-ARM AND LEG — 49.0 — $\frac{857}{1759}$

TOTAL UPPER EXT. — 24.0 — $214$ ← NO AMPUTATIONS $\overline{892}$ ← NO. VASCULAR INJURIES

TOTAL LOWER EXT — 49.6 — $\frac{774}{1561}$

SUBCLAVIAN THROUGH BRACHIAL — 28.3 — $\frac{197}{696}$

ILIAC THROUGH POPLITEAL — 62.1 — $\frac{660}{1063}$

0    20    40    60
PERCENT OF TOTAL

CHART 9.—Effect of site of arterial wounds of the extremities on incidence of amputation in American battle casualties in World War II.

INCIDENCE OF AMPUTATION FOLLOWING WOUNDS OF
BRACHIAL AND FEMORAL ARTERIES ABOVE AND BELOW
THE PROFUNDA BRANCHES

BRACHIAL ARTERY

FEMORAL ARTERY

PERCENT 80

PERCENT 80

81.1

60

60

55.7

56.1

54.8

40

40

26.5

25.8

20

20

NO. OF AMPUTATIONS

NO. OF CASES

$\frac{159}{601}$  $\frac{54}{97}$  $\frac{54}{209}$

$\frac{275}{490}$  $\frac{86}{106}$  $\frac{97}{177}$

0

0

TOTAL ABOVE BELOW
PROFUNDA

TOTAL ABOVE BELOW
PROFUNDA
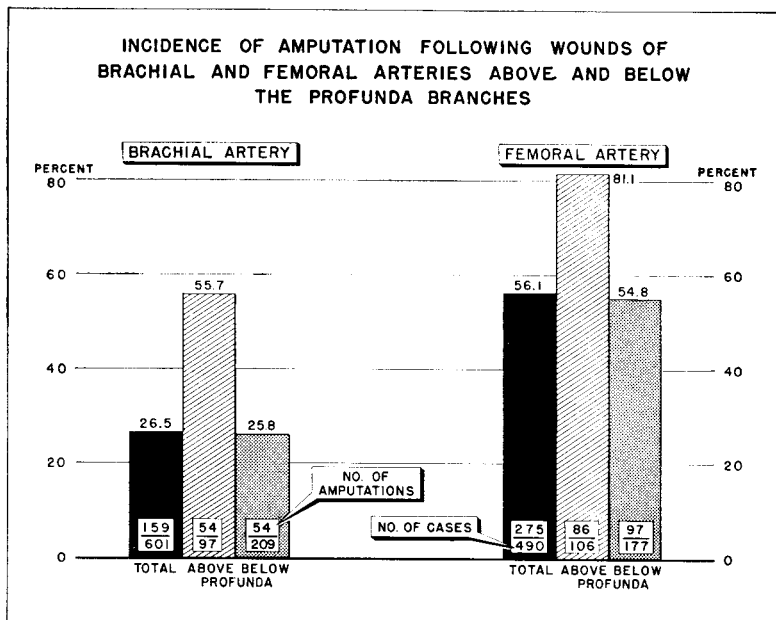
CHART 10.—Effect of site of wounds of the brachial and femoral arteries on incidence of amputation in American battle casualties in World War II. The 27 cases involving the profunda femoris (Table I) have been excluded as not pertinent to this consideration.

In the American material, in the 620 cases in which the records were suffi-
ciently explicit to permit separation of the injuries into distinct categories
(Chart 11), the incidence of amputation seemed definitely related to the type
of lesion. It varied from 25 per cent in spasm to 70.5 per cent in thrombosis.
A high incidence of poor results would be expected in the thrombotic category,
since this type of lesion is likely to cause widespread interference with the flow
of blood through the collateral vessels. In the category of spasm are included
the few cases of contusion which were recorded as such, because contusion,
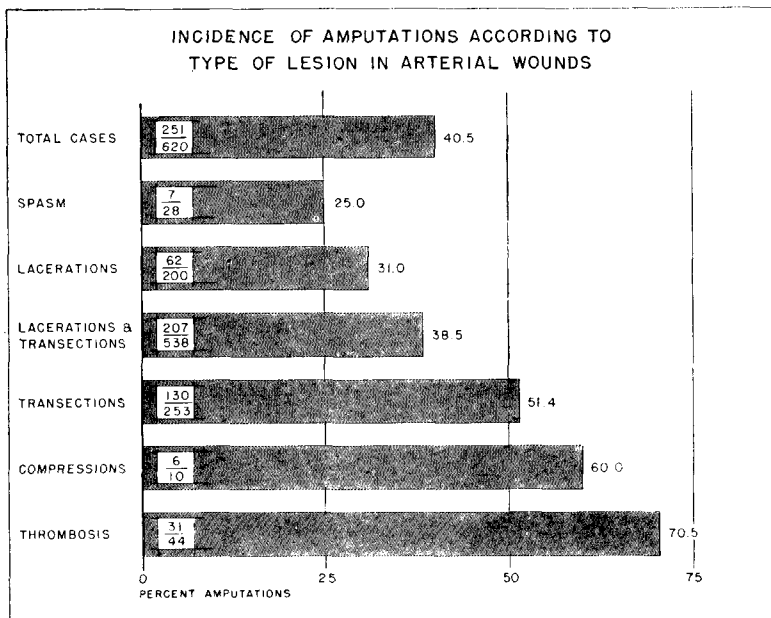


CHART 11.—Effect of type of arterial wounds of the extremities on incidence
of amputation in American battle casualties in World War II. The total num-
ber of lacerations and transections is greater than the sum of the individual
lesions in this category because it could not be determined from 85 of the records
which of these particular lesions was present.

if it is recognized at all, is not infrequently accompanied by spastic phenomena.
This type of lesion, however, is usually not recognized (and, therefore, not
recorded) and is usually slight. Its inclusion in a tabulated series is, therefore,
likely to alter the results favorably, which is perhaps one reason why Makins'
figures, which include contusions, are so much better than other series which
omit them. Some doubt exists as to the incidence of 25 per cent of amputation
in spasm. These figures are undoubtedly weighted, for in one sample of six
cases, there were five instances of gangrene. This is so contrary to the usual
experience as to suggest that the diagnosis of spasm was probably not correct
in one or more of the cases in this group.

The majority of cases of laceration in this series (Chart 11) were serious.

Minor lateral lacerations, in which conservative surgery was possible, were relatively few.

The category of lacerations and transections (which includes the 200 cases of lacerations, the 253 cases of transections, and a number of cases in which it could not be positively determined which of these lesions was present) presents an incidence of amputation which, as would be expected in view of its composition, lies midway between the incidence in lacerations, in which there may be a limited interference with the circulation, and the incidence in transections, in which there is abrupt interruption. Clean-cut transections were not the rule, there being tearing and loss of substance in most cases, associated with extensive damage to the collateral circulation.

The compression category includes only a small number of cases, so that the results are not statistically significant. Experience shows, however, that this is a very important group, because such injuries commonly complicate fracture and posterior displacement of the lower end of the femur. If this type of fracture, with its associated arterial lesion, is recognized and appropriate corrective steps are taken promptly, the complications which result from arterial compression can be avoided.

It seems scarcely necessary to elaborate further the importance of the type of wound in relation to the possible surgical procedure. As already intimated, the location and the type of the injury determine above everything else what the surgeon can do. The great majority of the wounds in the World War II series were produced by shell fragments, were large, were associated with extensive destruction of tissue, and (Charts 8–10) were not favorably located (Fig. 2). As a result, the vitality of the limb was gravely impaired before the surgeons ever saw most of the patients, thus jeopardizing the potential benefits of any therapeutic procedures employed.

*Infection.*—Infection is perhaps the least important of the limitations on therapy imposed by the circumstances of modern warfare. All battle wounds are potentially infected, it is true, but if adequate débridement can be done, surgical procedures directed toward the treatment of the vascular injury can be done at the same time with a high degree of safety. It is not infection, but the other circumstances just outlined, which now prevent reparative procedures in most battle injuries of the blood vessels.

It is granted that the views expressed in this section are extremely pessimistic. They are, however, equally realistic. In their defense it may be said that military surgery can be conducted only on a basis of profound realism, and that war is never a cheerful business.

### THE RESULTS OF ACUTE OCCLUSION
### LIGATION OF THE MAJOR ARTERIES

The results of acute occlusion of major arteries in war wounds, whether caused by the injury itself or by ligation of the injured vessel, have not been clearly established. There are a number of explanations for the confusion which still exists on this subject.

Perhaps the most important reason is the fact that statistics generally quoted as representing the incidence of gangrene after acute traumatic occlusion actually represent no such thing, since most of them include instances of aneurysm as well. The two lesions are, of course, totally dissimilar. In acute occlusion (ligation) the blood flow is cut off abruptly. In aneurysm the occlusion occurs gradually, if at all, and by the time it has developed, or the aneurysm is excised, a more or less adequate collateral circulation exists.

Furthermore, in many series gangrene is the only unfavorable result recorded. The percentage of cases in which primary amputation had to be done because of the arterial injury is completely disregarded, and such series, therefore, do not truly represent the incidence of poor results in acute traumatic arterial occlusion. As for the various series in which amputation is included, the range is so clearly unreasonable—in popliteal arterial occlusion, for instance, it varies from o to 1oo per cent[142, 157]—it is difficult to determine on what possible basis the calculations have been made.

Makins'[128, 129] statistics, which represent the largest collective experience in World War I, furnish an excellent example of the confusion which results from the inclusion of both acute and nonacute (aneurysmal) lesions in a single series. Actually, 49 per cent of his cases are aneurysms, and in certain vessels, such as the axillary and subclavian arteries, the proportion of nonacute lesions is more than 70 per cent. When (so far as possible) the favorable influence of aneurysm is excluded, his proportion of poor results rises from 18.1 per cent to 26.5 per cent. Yet his figures are repeatedly quoted, without qualification, as showing the incidence of gangrene after acute arterial occlusion. A similar lack of clarity is evident in the series collected by Salomon, Soubbotitch and others.[15, 51, 69, 71, 72, 74, 77, 78, 83, 102, 104, 175, 211,]   On the other hand, among 74 acute arterial lesions collected by Franz from German World War I statistics, the percentage of gangrene was 70.4. Mocquot and Fey also emphasized the gravity of these wounds, reporting an amputation incidence of 44 per cent among 61 they observed in a French Surgical Ambulance.

No large series of cases is available from the period prior to World War I to show the effect of ligation of major arteries in acute injuries. Sencert,[187] using statistics published before 1914, reported that the incidence of gangrene under these circumstances ranged from 5 per cent in the subclavian and brachial arteries to 50 per cent in the common iliac artery, the astonishingly wide range being explained, as the author himself pointed out, by the inclusion in the series of both aneurysms and acute occlusion.

On the basis of his personal military experience, Sencert[188] reported, in 1918, that ischemic gangrene had occurred only twice in 70 cases of vascular injury in which ligature was done a few hours after injury and in which no hematoma of any significance was present. The figures are confused, however, by the inclusion of four cases in which only veins (two internal jugular, two popliteal) were injured. When a diffuse hematoma had formed, the results were much less satisfactory; of 20 cases in which the axillary, femoral and

popliteal arteries were involved, gangrene developed in six. Sencert's own pronounced views as to the important rôle of hematoma formation in arterial injuries perhaps make the figures somewhat selective.

The results in Makins'[128, 129] British cases collected in World War I are considerably better than the American figures collected in World War II (Chart 8, Table I). The data, however, are not fairly comparable, for a number of reasons: (1) The American figures include only acute lesions, while, as already noted, the British figures include both acute and nonacute lesions. (2) In 85 per cent of the American material the wounds involved important or critical arteries, while this was true of only 70 per cent of the British material (Chart 5). (3) It is possible, though exact statements cannot be made on this point, that there are excluded from the British figures some cases of gangrene and amputation which were classified as infections rather than as vascular injuries, as well as cases in which amputation was necessary for extensive trauma and other complications of vascular injuries. The American figures include among the poor results all the cases in which amputation was necessary after vascular injuries, whether as the result of complicating infection, so-called toxic absorption, gas gangrene, or any other cause. (4) Because of the more destructive weapons used in World War II, it may be assumed that tissue destruction was greater in the American cases of World War II than in the British cases of World War I. As a result, in addition to the main arterial injury, the collateral circulation was frequently and seriously impaired. (5) Because the wounds of World War II were more extensive than in World War I, débridement, which probably was more commonly practiced in the war just ended was a more extensive procedure. This comment must not be misunderstood. Débridement is an essential procedure, the omission of which would undoubtedly have resulted in a higher mortality rate, as well as in the loss of more limbs from infection. When properly done, however, it involves loss of tissue, and in extensive wounds its thorough performance inevitably entails additional damage to the collateral circulation.

As a matter of fact, although the American results in World War II at first glance seem to be much worse than the British results in World War I, they are probably better. The British series, as has been pointed out, includes a large number of cases of aneurysm, which are excluded from the American series, and in which, as Elkin[59, 60] and Shumacher have shown, postoperative gangrene is rare.*  In World War II the British surgeons have not been encouraged by their own results. At the Cairo Conference, in 1943, Ogilvie stated that in the course of the war he had not seen a single instance of ligation of the popliteal artery which had not been followed by gangrene, and Blackburn, in 1944, in a discussion of surgery in the Field, stated flatly that ligation of the popliteal vessels, in particular, almost invariably leads to amputation above the knee a few days later.

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* In the combined series of 595 cases of aneurysms reported by these authors there was only one case of gangrene following operation.[59, 190]

### THERAPEUTIC MEASURES IN WAR WOUNDS OF THE ARTERIES
### LIGATION

From the preceding discussion, it clear that no procedure other than ligation is applicable to the majority of vascular injuries which come under the military surgeon's observation. It is not a procedure of choice. It is a procedure of stern necessity, for the basic purpose of controlling hemorrhage, as well as because of the location, type, size, and character of most battle injuries of the arteries.

From the technical standpoint, with reference to the optimal site for ligation, little discussion is necessary. At the present time, when wound infection is usually a controllable complication and when secondary hemorrhage is, therefore, not the factor of risk which it was in World War I, there seems no justification whatever for the performance of proximal ligation. It may be theoretically desirable to ligate at such a level as to avoid the creation of a blind pouch, but the deliberate effort to do so frequently involves extensive dissection and may still further jeopardize the circulation of the injured limb. The proposal was first made by Leriche and Policard, in 1922, and was reëmphasized by Holman,[87] in 1944, and Rogers, in 1945.

*Ligation of the Concomitant Vein.*—The chief difference of opinion concerning the technic of ligation has to do with whether or not the concomitant vein should be ligated along with the injured artery. The amount of space devoted in the literature to this discussion seems curiously out of proportion to the value of the procedure, though the manner in which the practice evolved is rather interesting, and has been thoroughly reviewed by Brooks.[25]

Prior to World War I the current opinion seemed to be that the prognosis for survival of a limb after interruption of a major artery was worse if the concomitant vein was injured and had to be ligated simultaneously. Jacobson stated that under these circumstances: "Leave should be gotten at once for amputation." Matas[131] declared that "the danger of peripheral gangrene is always made doubly worse by the simultaneous injury of the accompanying or satellite vein." During World War I, however, a completely opposite point of view developed, with Makins as the originator and chief proponent of the practice for war wounds. Simultaneous ligation of the concomitant vein, in his opinion,[128, 129] is of distinct advantage for two reasons: 1. The capacious main vein affords too ready a channel of exit for the diminished arterial supply, as well as an undesirable reservoir of stagnation. 2. As the result of combined arteriovenous ligation, the smaller amount of blood supplied by the collateral arterial circulation is maintained for a longer time within the limb, and there is, therefore, an improvement in the conditions necessary to preserve its vitality.

Therapeutic venous ligation for venous disease has been known since the time of Hippocrates, but Makins seems first to have proposed it as part of the treatment for acute traumatic arterial lesions. He observed from his experiences in the South African war that a smaller incidence of gangrene followed traumatic arteriovenous fistula when both artery and vein were ligated than

when only the artery was ligated, though, as Brooks[25] pointed out, he did not
record the observation until his Bradshaw Lecture, in 1913.[124] Of further
interest in this connection is the fact that Makins[125] seemed still unprepared to
advocate the procedure in his extensive article on vascular injuries of warfare,
published in 1916, and simply stated: "With regard to the question of the
danger of simultaneous ligature of the artery and vein, it may be added that
this was done in one of the successful cases." In the Hunterian Oration,[126]
however, which was delivered in 1917, he advocated the deliberate ligature of
the uninjured concomitant vein in cases of arterial occlusion, and at this time,
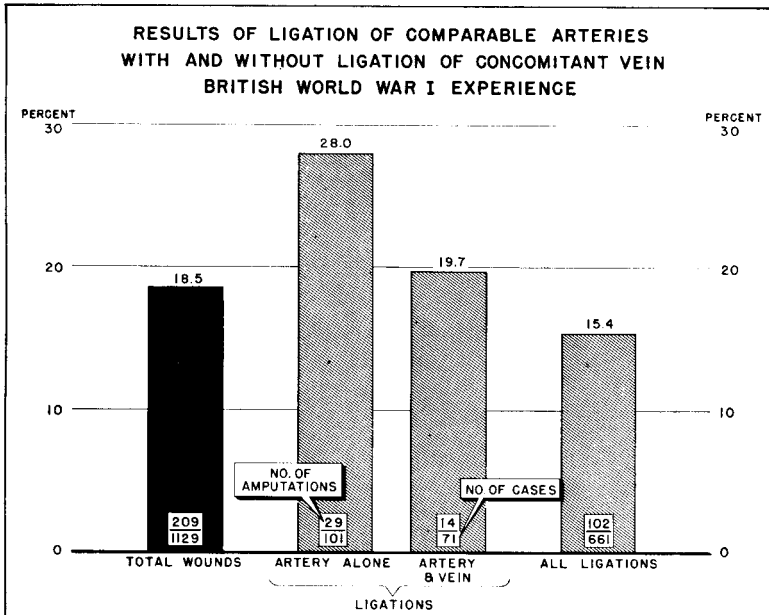

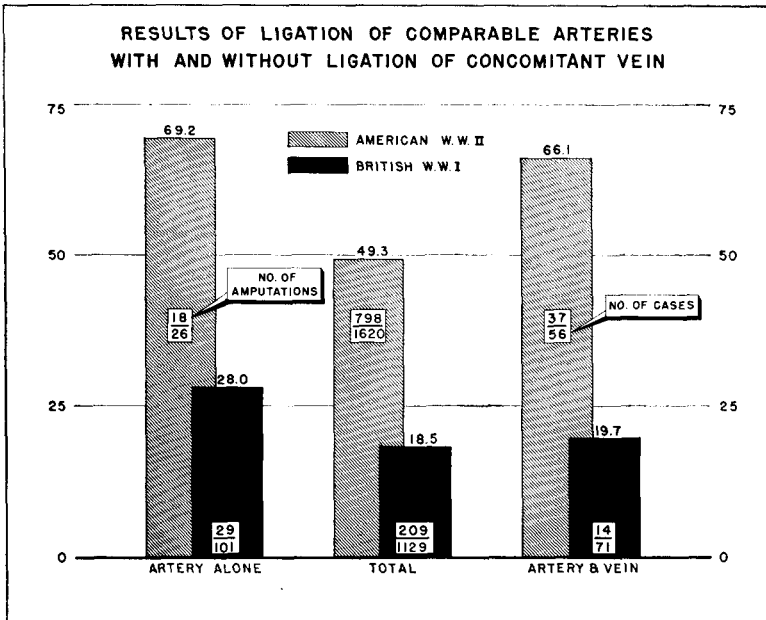
CHART 12.—Results of ligation of comparable arteries with and without
ligation of concomitant veins in British casualties in World War 1.

as well as in his monograph[128] published after the war, he set forth the evidence
on which he based the suggestion and which may be briefly recapitulated
as follows:

1. The demonstration in varicose veins of the ease with which a compensa-
tory balance is attained when blood is diverted from the larger channels.
2. The lack of permanent vascular difficulties when the jugular and other large
veins are ligated to prevent the diffusion of septic emboli.   3. The possibility of
survival after occlusion of the vena cava.   4. His personal experience in
arteriovenous fistula to the effect that quadruple ligation and excision are
followed by less risk than simple arterial ligation. 5. Von Oppel's[158-161] good
results in six cases of occlusion of the popliteal vein in senile gangrene, on the
basis of his observation of the occasional good results which follow arterio-
venous anastomosis in this condition and which he attributed to control of the
venous circulation and the subsequent rise in the blood pressure of the limb.

6. Drummond's experimental demonstration that gangrene follows ligation of the mesenteric artery but not ligation of the mesenteric artery and vein.  7. Van Kend's experimental studies, which showed that local blood pressure was raised in the affected limb when the concomitant vein was ligated subsequent to occlusion of the artery.

The matter was fully discussed at the Inter-Allied Conference of Surgeons, held in Paris in May, 1917, and on the ground of Makins' statistics (Charts 12 and 13) the view was advanced that the concomitant vein should be ligated whenever a major artery was ligated, even if the vein itself was not injured.[47, 93, 127] Some surgeons[46, 135, 136] have accepted this view with some-



CHART 13.—Results of ligation of comparable arteries with and without ligation of concomitant veins among British casualties in World War I and American casualties in World War II.

thing less than enthusiasm; Maurer, for instance, wrote, in 1921, that concomitant vein ligation is not harmful and might be advantageous, and, in 1939, he had become even less enthusiastic. But the weight of Makins' prestige was so great that for the most part his point of view was accepted without question, and the practice of ligation of the vein became the rule when the artery had to be ligated.[13, 14, 41, 51, 71, 72, 93, 144, 145, 188, 189, 201.]

Brooks, in an extensive review of the subject, in 1929, decided on the basis of clinical and experimental evidence[28, 88, 166, 198] that the concomitant vein should be ligated if the popliteal or axillary artery were injured, but that primary venous ligation should not be done if the common femoral artery were ligated, although subsequent ligation of this vein is recommended if signs of impending gangrene become evident. He considered that it made

little difference whether the procedure were performed or omitted if the femoral and brachial arteries were affected. More recently, additional experimental evidence to support this thesis has been published.[117a] Wilson, on the basis of an experimental study published in 1933, stated that his own results did not support the current belief that ligation of the concomitant vein diminished the incidence of gangrene following ligation of the main artery, and added that if the venous ligation were done at a higher level than the arterial ligation, the incidence and extent of tissue death would be increased. This receives indirect support from the observations of Montgomery[148] who found that the per-minute flow of blood to the extremity was reduced further following ligation of the concomitant vein in the extremity in which the artery had been previously ligated. The following year Brooks and his associates[27] published the results of an experimental study of 220 rabbits, 200 of which showed that massive gangrene of the extremity was 14.5 times less frequent after arterial and venous ligation than after arterial ligation alone, from which Brooks and his coworkers concluded that concomitant vein ligation was beneficial. Whereas this may be true for the rabbit, these results do not conform with those observed in man, as will be pointed out below.

While the experimental evidence for and against ligation of the concomitant vein is not always consistent, there seems no doubt, as Wilson has pointed out, that Makins' reasoning in favor of the procedure is not based upon sound physiologic concepts. Makins' often-quoted figures, furthermore, do not seem to warrant the sweeping conclusions which have been drawn from them. For one thing, the proportion of cases of arterial and of venous involvement is not clear, nor is the proportion of aneurysms in the two groups of cases. For another, the difference in the incidence of amputations (Chart 12) between the series in which only arterial ligation was done and the series in which the concomitant vein also was ligated is not statistically significant. Finally, the incidence of amputations in the whole group of wounds of comparable arteries in Makins' collected World War I series is actually less than the incidence of amputations in the series in which the concomitant vein was ligated, though the former series, on the basis of his theories, should provide the larger number (or at least an equal number) of poor results (Chart 12).

Aside from Makins' figures, not a great deal of evidence for or against ligation of the concomitant vein can be found in the literature of World War I. In 1916, which, it is of interest to observe, precedes the published views of Makins on this subject, Sehrt reported the incidence of gangrene in the upper extremity to be 7.8 per cent when the artery alone were ligated and zero per cent when the artery and vein were concomitantly ligated. The corresponding figures for the lower extremity were 20.4 per cent and 9.0 per cent. The numbers of cases are not given. On the basis of this experience, Sehrt concluded that concomitant vein ligation was of distinct value and expressed the belief that "impounding of blood (venous) in the extremity is beneficial." Propping, in 1917, influenced by these observations, attempted to provide experimental evidence to support the opinion that concomitant vein ligation is beneficial and

while the experiment was rather naive be concluded from it that gangrene of a limb after ligation of an artery is the result of an imbalance between the amount of blood entering the extremity and the amount of blood leaving it through the veins. In 1921, Heidrich, on the basis of 698 cases collected from the literature, concluded that the results were better when the concomitant vein was ligated. The incidence of aneurysm in these cases, however, was extremely high, which vitiates their significance. On the other hand, Punin stated, in 1921, on the basis of 64 personal and 1,057 collected cases, that the incidence of gangrene after the combined procedure was no less than when ligation of the vein was omitted. Brooks, in 1929, regarded the procedure not only as of no value but actually contraindicated.

The American experience in World War II (Chart 13) is not extensive. The majority of surgeons did not use concomitant venous ligation routinely, if at all, and the experiences of single surgeons are, therefore, insufficient to determine, one way or the other, the influence of the method on the end-results of vascular injuries. The collected figures seem to indicate that it does not in any way increase the chance of survival of the limb. The difference between the incidence of amputations in the series in which the vein was ligated and in the series in which it was not ligated is not statistically significant. The incidence of amputation in the total wounds of comparable arteries was considerably less than that in the group in which it was known that concomitant vein ligation was done, the difference being statistically significant, though, as was pointed out for the British figures, one would expect the results to be as good, if not much better, when venous ligation was done were the procedure of definitive value.

The conclusion seems legitimate, on the basis of Makins' figures for World War I and the American figures for World War II, that ligation of the concomitant vein furnishes no protection whatsoever against the development of gangrene after acute arterial occlusion and ligation in battle casualties.

### SUTURE REPAIR

In addition to ligation, which permanently interrupts the flow of blood through the main channel, arterial wounds have been treated by suture, vein graft, and tube anastomosis. The consensus, at least on theoretic grounds, is that suture repair offers the greatest hope for survival of the limb, but practically, as has been pointed out, reparative measures are seldom applicable to such wounds. The operation should always be considered, however, circumstances permitting, for small lateral wounds, while less often it is a possibility in larger lateral wounds or in incomplete or complete transection.

The theoretic value of suture was recognized during World War I, but it was also realized that the number of cases in which it was possible were extremely few. Sencert wrote, in 1918, that ligature was the method *par excellence* for the arrest of hemorrhage from recent vascular wounds and that the indications for suture were exceptional. Makins stated that suture is the only method which provides ideal results, but added that it is applicable only in the primary stage and only if infection can be avoided. He regarded lateral wounds

of the larger vessels, that is, the carotid, brachial, iliac, femoral and popliteal arteries, as most suited for the method.

Bernheim,[13, 14] who had enthusiastically practised the Carrel method of suture in his civilian work, went to France with an elaborate personal equipment to use it in military surgery. In nearly two years overseas, however, at installations of various levels on several American fronts, he never saw any other surgeon perform it and he himself discontinued it in the few cases in which he attempted it, because of loss of supporting tissue as the result of necessary débridement and because of the unjustifiable amount of time which the operation required. Even in the case in which infection was absent he thought that military circumstances were unpropitious for vascular suture, while "only a foolhardy man," he remarked, "would have essayed suture of arterial or venous trunks in the presence of infections such as were the rule in almost all the injured."

Goodman[70-73] wrote enthusiastically of the advantages of suture, and stated that during a month's stay on the British Front in 1917 he was "enabled to refute the deductions made by the other surgeons present," the deductions being that the risk of gangrene after arterial ligation was sufficient to justify immediate amputation in injuries of the femoral, popliteal, and even the posterior tibial arteries. His personal experience, however, was limited to five cases, in one of which gangrene developed and amputation was required.

Not many other reports concerning the use of immediate suture in acute arterial wounds are available in the literature from World War I.[57, 77, 78, 83, 96, 135, 144, 145, 187, 189, 194, 195] Makins[128, 129] was able to collect only 39 cases. Three patients died, all from infection, and ideal to good results were obtained in about half of the remaining cases, the results being "in no way inferior to ligature," which seems somewhat faint praise. Goodman,[71-73] in addition to his own personal cases, presented a number of collected cases but the large number of aneurysms included in the group makes the figures of little value for comparative purposes. His collection includes a number of cases from the German literature, and there seems no doubt that German surgeons used suture more frequently than either British or American surgeons, though many series, such as that reported by von Haberer,[77, 78] consist chiefly or entirely of aneurysms. Gnilorybov, writing in 1944, stated that during World War I he had had several good results from vascular suture and that he saw no instance of gangrene after its use, in contrast to ligation, after which half of his cases developed gangrene. He did not cite exact figures.

The thorough débridement practiced in World War II, supplemented by chemotherapeutic methods, lessened the fear of infection which presumably discouraged a wide use of vascular suture in World War I. Nevertheless, the number of instances of vascular injuries in which suture was practised continued to be very limited, for the reasons already mentioned, that lateral wounds sufficiently localized to permit suture repair were seldom seen, and that the majority of wounds were accompanied by such widespread destruction of tissue and such loss of arterial substance that end-to-end anastomosis was rarely feasible.

INJURIES OF ARTERIES IN WORLD WAR II

The performance of suture was recorded in only 81 cases in the entire series of 2,471 arterial wounds which indicates the relative infrequency of the practicability of this procedure (Chart 14). Included in the group are three end-to-end anastomoses, of the common femoral, femoral, and popliteal arteries, respectively. Most of the cases were small lateral lacerations, involving a third or less of the circumference of the vessel. It is of interest that only one case in this series was a bayonet wound, and it was accidental; bayonet wounds, because they are cleanly incised and involve no great loss of tissue, would seem to be ideally suited for suture.
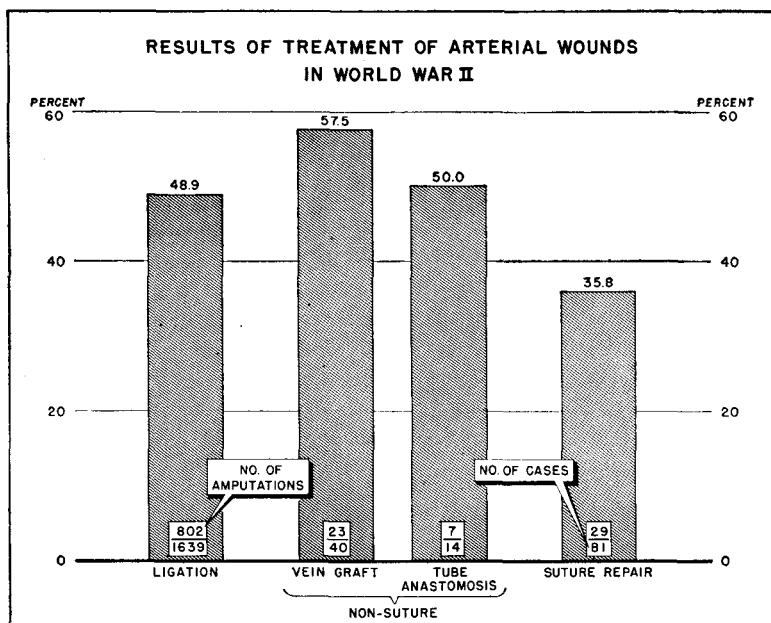


CHART 14.—Results of various therapeutic measures on incidence of amputation in arterial wounds of the extremities in American battle casualties in World War II, with special reference to the type of arterial repair.

The results of suture in these 81 cases are significantly better than the results of ligation in a larger series of 1,639 cases (Chart 14) and, indeed, are better than the results of any method of treatment employed. Not too much encouragement must be derived from these facts, however, for these cases formed a highly selective group of minimal wounds, without extensive tissue destruction. It would not be possible to duplicate or even to approach these results in the usual run of arterial wounds.

*Complications.*—The most important immediate complication of vascular suture is hemorrhage. The records are incomplete on this point, but secondary hemorrhage is known to have occurred in two of 24 cases included in the series of 81 cases in which suture was employed. Hemorrhage is usually a late development, occurring six to eight days after operation, by which time a collateral circulation has usually developed, so that ligature can be done with much less

risk to the limb than when it is a primary procedure. Thrombosis and embol-
ism are other immediate but less frequent complications. They were not
recorded in any case in this series. Late complications include arterial stric-
tures and aneurysms; at the present writing the follow-up on the cases in this
series is incomplete, and no statements can be made concerning their develop-
ment following arterial suture.

### OTHER REPARATIVE METHODS

   Because of the extremely destructive weapons used in World War II,
arterial wounds were often associated with extensive loss of substance. In the
small number of such cases in which arterial ligation did not seem promptly
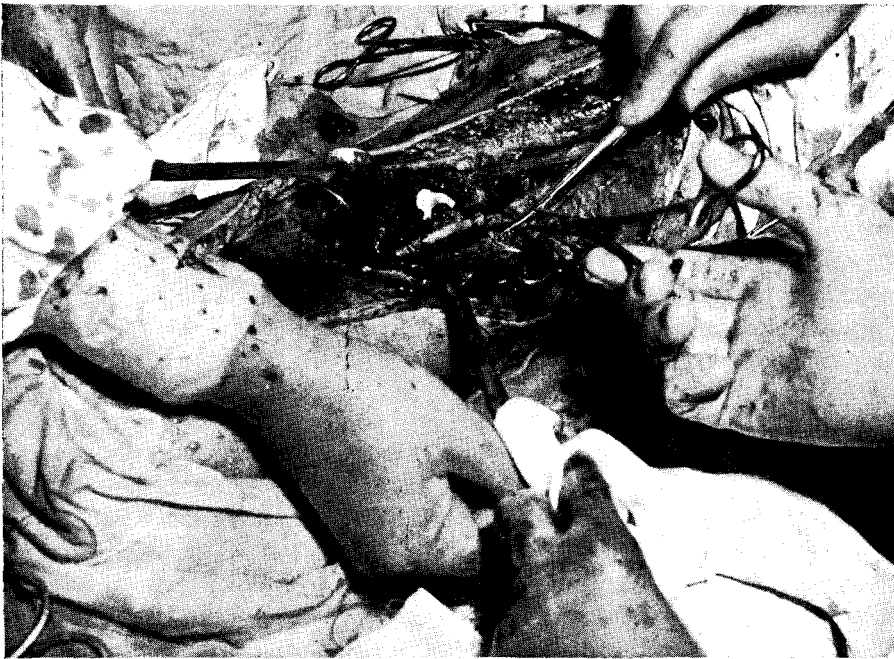


FIG. 1.—Completed nonsuture vein graft anastomosis of popliteal artery. The arterial
injury was complicated by a severe compound fracture of the tibia through the knee joint
and the dislocated tibial fragments are still attached in the wound.

indicated and in which suture repair was clearly impossible, some method of
bridging the gap was considered desirable in order to restore continuity of the
artery. Various methods have been suggested and practiced for this purpose,
including the use of vein grafts and prosthetic tubes.
   Sutured, as opposed to nonsutured, vein grafts had been suggested as a
possible method of repair and successfully performed experimentally[70, 76, 150, 151]
as well as clinically[117, 207] some years before World War I. Although the pro-
cedure does not seem to have been performed for acute arterial occlusion during
that war, it was employed for traumatic aneurysms with surprising success.[4, 23,
72, 73, 92, 178, 189, 207, 211] In a series of 47 cases reported by Warthmüller, 40

were considered successful. As Matas[133] emphasized: "There is scarcely any need of grafts" for the type of case in which it was usually employed in light of the development of the technically simpler and highly successful Matas operation. To our knowledge the method was not used for these injuries in any American military installation in World War II. Because of technical and other difficulties, it has a very limited application, but a few successful clinical cases have been reported during this war, such as the seven cases each by Rehn [176, 177] and Killian, the six (of 10) by Schneider and Batzner, the single case by Murray,[152] and the unstated number by Khenkin. The majority of these cases were done on patients with aneurysms rather than acute arterial wounds.

The principle of nonsuture anastomosis originally developed by Payr, in 1900, thoroughly tested experimentally by Höpfner, in 1903, and successfully applied clinically by Lexer, in 1907, was employed by Blakemore, Stefko, and Lord,[18-21] in 1942 as a method of restoring the blood flow through severed arteries. They used vitallium tubes instead of magnesium alloy tubes which Payr and Höpfner had used, lined them with vein grafts, and tied the cut ends of the artery over the ends of the connecting cannula. Later they modified the method, using two tubes bridged by a vein graft, just as Höpfner had done. Their experimental and clinical results were highly encouraging and they were enthusiastic over the possibilities of the method in military surgery. Of historical interest, also, is the fact that Jeger,[95] in 1913 had advocated the method in military surgery.

During the recently terminated war, the Surgical Consultants Division in the Office of the Surgeon General supplied these vitallium tubes in assorted sizes to the various Theater Consultants, who distributed them to experienced vascular surgeons for trial in Forward Installations. Full details are not yet at hand, but the material analyzed in this communication shows that the double-tube-vein-graft technic (Fig. 1) was employed in 40 cases. The incidence of amputation was somewhat greater than after other methods of repair but the difference is not statistically significant (Chart 14).

A consideration of great importance in military surgery is the ease with which an operation can be performed, and experience indicates that nonsuture anastomosis is neither as simple nor as easy as its proponents, whose experience, of course, is extensive, state it to be. One operation, for instance, performed in an Evacuation Hospital, by a better-than-average surgeon, took three and one-half hours; in the course of the procedure the ligature twice slipped off the tube and had to be tediously reapplied. Complete information is not available as to the number of times this method of anastomosis was attempted but could not be completed, though it is known that this happened five times in one sample consisting of 23 cases. A possible disadvantage of the method in cases in which it cannot be completed is that additional arterial substance may be destroyed in the course of the attempted application of the tube (Fig. 2).

Bridging of the arterial gap by intubation to provide for temporary maintenance of the blood flow is a fairly old principle. In 1915, Tuffier, who rea-

soned from his experiences with the use of silver tubes in performing direct
blood transfusion, proposed the use of these tubes for bridging arterial defects
and was successful in a number of cases. Makins, in 1922, reported 12 cases
treated by this method, four of which, however, were not acute lesions. One
patient died of sepsis and one of gas gangrene, but the results were good in the
remaining cases. Makins also mentioned Cowell's case, in which, following



FIG. 2.—Arteriograph 1.5 weeks after nonsuture anastomosis of
popliteal artery, showing complete obstruction of the anastomosis.
This case illustrates the possible damage to important arterial
branches if too much of the artery is used in the anastomosis. The
limb might not have survived if the branch to the gastrocnemius
soleus group of muscles had not been spared. (Operation by Har-
bison and Simeone.)

ligature of a completely divided femoral artery, signs of gangrene ensued but
the limb was saved by removal of the ligatures and the application of a Tuffier
tube. The generally favorable opinion of the procedure is reflected in the writ-
ings of a number of authors during that period.[24, 52, 72, 92, 128, 129, 201, 202]

To accomplish the same objective as the silver tubes used in World War I,

glass tubes were suggested early in World War II.[134] While it is known that they were used by British and Canadian surgeons during this war, no details concerning their experience are available at this writing. The potential clinical value of the method was indicated by the successful experience of Murray and Jones in their experimental studies with heparin on dogs.

Plastic tubes were also suggested and employed in a similar manner as glass tubes. In the material analyzed there were 14 cases in which this method of repair was employed. Although the results obtained in this group of cases are not much different from those following other forms of repair, the series is


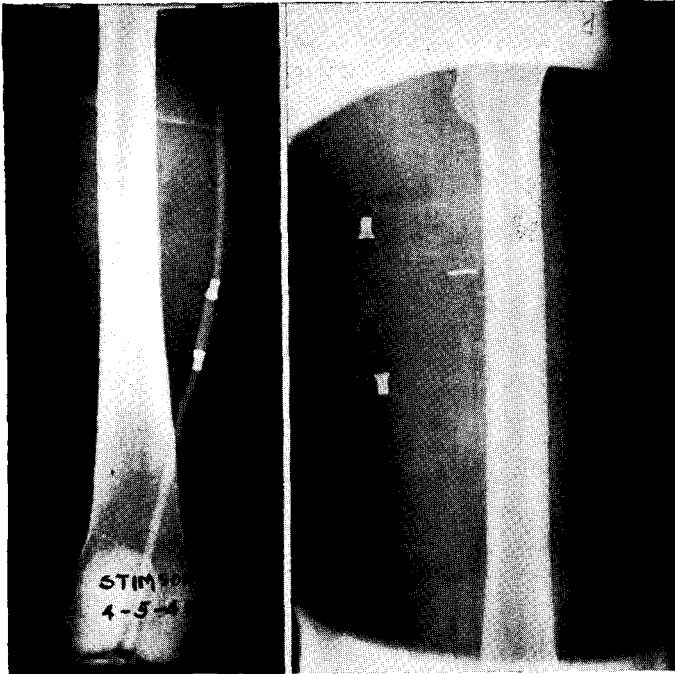
FIG. 3                               FIG. 4

FIG. 3.—Arteriograph 3.5 weeks after nonsuture anastomosis of superficial femoral artery, showing patency of the anastomosis and no evidence of undue ballooning of the vein segment. Clinically, the patient showed excellent peripheral circulation. (Initial operation at 8th Evacuation Hospital.)

FIG. 4.—Roentgenograph after nonsuture anastomosis of superficial femoral artery. The extent of the defect which may be bridged, as shown by the positions of the vitallium tubes in this instance, is often considerable. The repair was successful.

obviously too small to permit definite conclusions (Chart 14). Plastic prostheses have certain advantages over other prosthetic devices used in the repair of arterial defects. They are apparently well tolerated by the tissues, and since they can be altered in size and shape to fit the necessities of the special case, merely by soaking the basic material in warm water, a supply of tubes of various sizes need not be kept on hand, as is necessary when vitallium or glass

tubes are used. The technic of repair by this method is also simpler than when vitallium tubes are used. On the other hand, the possibility of thrombosis is probably greater than that following the use of vein grafts (Fig. 3).

The object of tube anastomosis in arterial injuries is the maintenance of the circulation of the injured limb while a collateral circulation is developing. If this objective can be achieved, the later gradual occlusion of the tube, with cutting off of the circulation in the main vascular channel, will have a much less deleterious effect than if these processes had occurred abruptly. To achieve the desired result, however, the patients must be seen early, and the irreducible time-lag, discussed elsewhere in this communication, makes this impossible in the majority of cases.
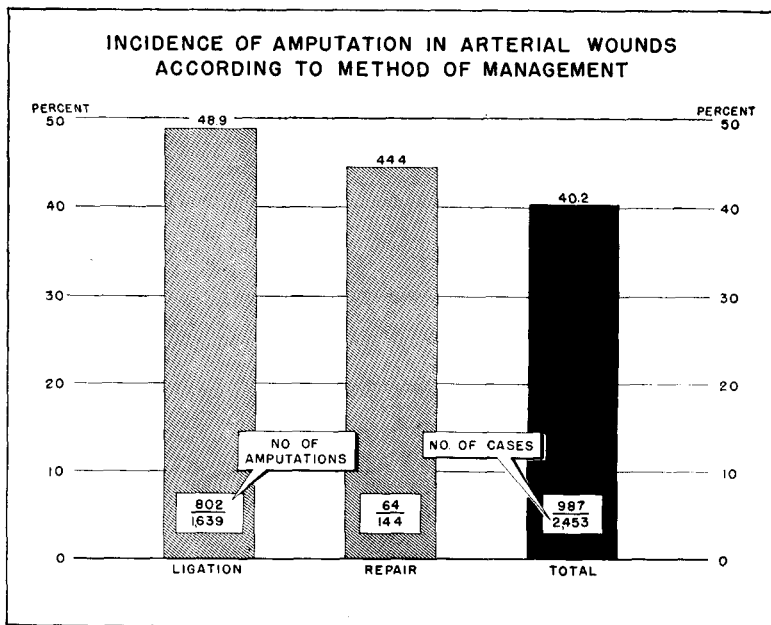


CHART 15.—Results of various therapeutic measures on incidence of amputation in arterial wounds of the extremities in American battle casualties in World War II.

A broader experience will be necessary to determine the usefulness of all nonsuture and other methods of arterial repair in war wounds. Individual cases (Fig. 3) can be cited in which it may be said that one or another method may have been responsible for the saving of all or part of a limb, but the overall figures (Chart 15) do not show sufficiently significant differences to warrant definitive conclusions. In all fairness, however, it must be said that the cases selected for trial were all cases in which suture repair was not feasible because of the size of the defect (Fig. 4) and in which the prognosis was grave, and the proportion of critical vessels involved was higher than in the series in which ligation was done.

### CONSERVATIVE (NONSURGICAL) THERAPY

For the sake of completeness a few words should be said about conservative (nonsurgical) therapy, which has been suggested for a small group of selected vascular injuries, in which it is hoped that uncomplicated healing will occur, or, if it does not, that aneurysm formation will take place. The almost negligible incidence of loss of limb after excision of aneurysms prompts the rather paradoxical statement that the best safeguard for the survival of a limb is to permit an acute arterial wound to develop into an aneurysm. The great majority of aneurysms occur accidentally, however, rather than as the result of deliberate surgical inaction. The principal objection to conservative therapy in battle injuries of the arteries is that it usually implies the omission of débridement, which is so essential a phase of the management of all war wounds that exceptions to its routine performance must be made with the greatest caution. Conservative therapy was advocated as a deliberate policy by some British surgeons[30, 61] at the Congress of C. M. F. Army Surgeons held in Rome in February, 1945, but few arterial wounds among American troops were deliberately treated by this plan. Three cases, in all of which the results were good, were treated conservatively by Sandzen and Evans in a series of 89 vascular wounds, 64 of which involved major arteries, and Rose, Hess and Welch treated eight of 100 cases in this way, also with good results. In four of the eight cases the wounded vessels were exposed during débridement, and in the other four instances, in each of which the popliteal artery was involved, they were not exposed at all.

The selection of cases for conservative management requires expert surgical judgment, as well as a good deal of courage. Generally speaking, it is best to explore even trivial wounds, with the idea of performing remedial or reparative surgery if there is evidence of complete interruption of the circulation.

### SUPPLEMENTAL THERAPEUTIC MEASURES

*Anticoagulant Therapy.*—Anticoagulant therapy, in spite of its value in selected cases in civilian surgery, has an extremely limited application in military vascular surgery. Its use immediately after wounding, as has already been pointed out, is impractical because its safe application demands that it can be used only in a hospital, where close clinical observation and repeated laboratory studies are possible. Mere arrival at the hospital, however, does not mean that anticoagulant measures can immediately be applied. They are not safe even then until (1) the patient has been properly examined and it has been determined that the injury is limited to the vascular wound, and until (2) the operation has been concluded. It may be theoretically possible to employ heparin or some similar agent before operation and to control the clotting time during the procedure, but it is doubtful whether even in a civilian hospital this would be a practical plan. In a military installation it would be neither practical nor safe.

In the last analysis, the time-lag between wounding and the safe period for the institution of anticoagulation therapy is likely to be so long that this measure is no longer useful when it could safely be applied: Thrombosis would

already have occurred and the distal portion of the extremity would have been deprived of blood for too long a period for the pathologic changes which occur in the absence of circulation to be reversible. On the other hand, in the individual cases of battle wounds in which anticoagulant therapy is indicated and conditions permit continuous, careful observation, with adequate laboratory checks, the method has a definite field of usefulness and should be employed. Data are not available as to how often anticoagulant therapy was used in vascular wounds by American surgeons in World War II, although it is known that it was employed only rarely. In one sample of 12 cases in which it was instituted (in some it was administered in Pitkin's menstruum)[118] as early as was considered feasible under the military conditions and in which careful studies were made no significant advantages were observed from its use.[192]

*Sympathetic Block and Sympathectomy.*—Considerable clinical and experimental evidence exists to show that vasospasm is a natural response to those forms of trauma which directly or indirectly affect vascular structures. Spasm of the major arteries in wounds of the extremities was recognized in World War I,[48, 55, 103, 105, 113, 136, 137, 189, 196, 205, 206] and has since been observed and studied clinically and experimentally.[11, 35, 37, 38, 66, 68, 79, 84, 90, 112,113, 116, 121, 147, 155, 172, 197, 209] The degree of vasospasm varies considerably, ranging from localized constriction with consequent minimal ischemia to a more extensive and generalized involvement, especially of the collateral circulation, with consequent ischemia of a degree sufficient to produce actual gangrene. Rational therapy in such cases is based upon an attempt to counteract vasospasm and to produce maximum vasodilatation in the involved extremity. Since the disturbance is apparently due to a vasomotor reflex initiated in the traumatized tissues, and since vasoconstrictor impulses are transmitted by way of the sympathetic nerve fibers, interruption of these impulses by means of sympathetic block or sympathectomy has been suggested and practiced by numerous observers.[16, 45, 66, 68, 75, 99, 100, 110, 113, 130, 155, 168]

Interruption of the sympathetic impulses usually by chemical means (procain hydrochloride), was widely practiced by American surgeons in World War II, but in the material available for analysis it was possible to determine in only 278 cases that the procedure had been performed or had been omitted. The results of the analysis (Chart 16) provide no substantial evidence that this method was of any value. The incidence of amputation in the group in which sympathetic block was performed is only slightly less than the incidence for the group as a whole, while the incidence in the cases in which ganglionectomy was done is greater than for the entire series.

These figures might seem to suggest that sympathectomy is a valueless procedure, but familiarity with the clinical material permits a different, and more accurate, interpretation: As a rule, sympathectomy was used only as a last resort, when it had already become apparent that the limb would not survive, while sympathetic block was more frequently instituted as part of the immediate postoperative routine, being continued until the outcome in respect to survival or death of the limb had become obvious. In the light of this knowl-

edge the apparently poor results of sympathectomy and the better results of sympathetic block are more readily understood.

The difficulties of evaluating such procedures as these on a purely statistical basis should also be emphasized: In the first place, the effective performance of the block is frequently open to doubt, and in the second place, proper objective methods are lacking to determine the efficacy of the procedure, while suitable controls upon which to base an evaluation of results are also lacking. The survival or death of the limb, which at first glance might seem to be a critically objective test, actually is not: It does not permit a clear decision as to whether the therapeutic measures employed in a given case have influenced the results, and it can serve as a criterion only when sufficiently large numbers of cases are available for statistical evaluation.



RESULTS OF SYMPATHECTOMY AND SYMPATHETIC BLOCK
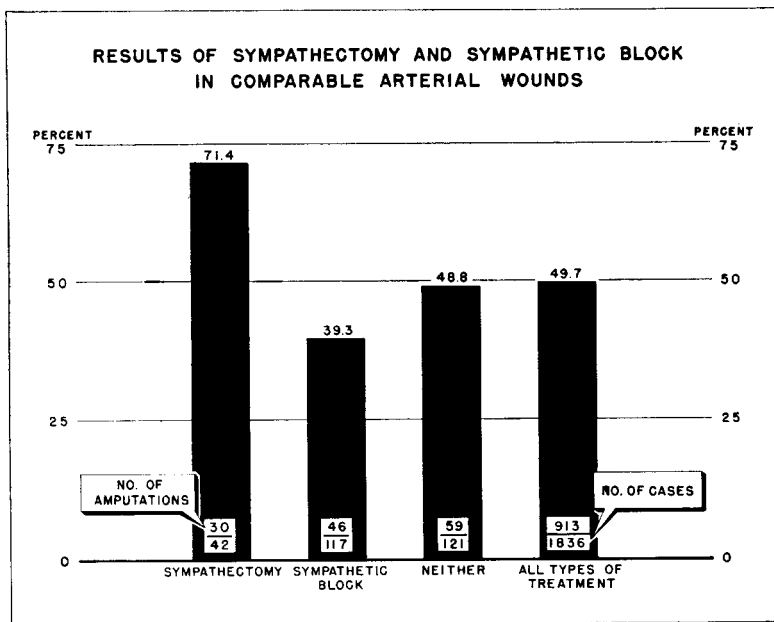IN COMPARABLE ARTERIAL WOUNDS

CHART 16.—Results of various therapeutic measures on incidence of amputation in arterial wounds of the extremities in American battle casualties in World War II, with special reference to sympathectomy and sympathetic block.

Perhaps the chief difficulty in critical evaluation of this method is the fact that in the great majority of arterial injuries the question of the viability of the part has been established at the time of wounding, and the margin within which improvement can be demonstrated is, therefore, so small that great numbers of cases are required to establish on a statistical basis the efficacy of any single procedure.

In spite of the lack of statistical data, however, there is considerable evidence in favor of sympathectomy and sympathetic block from personal experience and from the experiences of other surgeons. Cases can be cited in which moderate degrees of tense swelling and muscle pain characteristic of muscular

ischemia have regressed and in which the temperature of the limb has improved following ganglionectomy. In fact, the statement is perfectly fair that the experiences of most American surgeons working in the forward areas are to the effect that sympathectomy and sympathetic block were useful and beneficial procedures, regardless of inconclusive statistical evidence to prove the point.

Cohen[38] has taken exception to the theory that arterial spasm is influenced by local or distant autonomic reflexes, on the ground that it is myogenic in origin. In addition, he has cited evidence suggesting that blocking of the vasomotor control of the wounded limb is dangerous, because, he concludes, vasodilatation in the skin is not accompanied by vasodilatation in the muscles, and harm is done by diverting the blood from the muscles into the skin. He, therefore, deprecates the use of sympathetic block or sympathectomy as a therapeutic measure to combat traumatic vasospasm associated with direct injury. Curiously, however, he advocates the use of sympathectomy to control vasospasm associated with a crushing injury or following the prolonged application of a tourniquet, on the ground that the vasospasm observed in these types of vascular injuries is of a reflex nature. There are two obvious inconsistencies in Cohen's reasoning. The first is his assumption that vasospasm can be initiated reflexly by one type of trauma and not by another, even though the end-results of both, insofar as tissue damage, as well as ischemia and its consequences, is concerned, are the same. The second is his assumption that sympathetic block or sympathectomy can be both injurious and beneficial for vasospasm initiated by different types of trauma.

*Fasciotomy.*—The tense, hard swelling of the muscles of the forearm and leg frequently observed after complete obstruction to the blood supply of those parts has been related to rigor mortis (Fig. 5). Actually the two conditions are not identical, since in ischemic swelling the muscles appear to be contained under considerable pressure by the enveloping fascia. Following interruption of the main arterial supply to the muscles of the affected limb, a vicious circle promptly develops, in which the impairment of the capillary circulation is increased by the swelling of the muscular tissue and the pressure of the enveloping fascia, while the swelling and pressure are themselves increased by the increasing impairment of the capillary circulation. Eventually a stage is reached at which circulation ceases entirely.

On the basis of these assumptions, fasciotomy has been recommended not only for cases in which ischemic swelling has already developed but also for incipient cases in which progression seems likely. Longitudinal incisions are used in both upper and lower extremities. In the leg the incision is made posteromedially to decompress the gastrocnemius-soleus group of muscles and anterolaterally to decompress the anterior tibial compartment. In the forearm the incision is made on the volar aspect.

Fasciotomy is open to criticism on the ground that the incision may destroy the collateral circulation from the skin and may further compromise the regional circulation by introducing the risk of infection. On more theoretical grounds, however, these objections are superseded by the consideration that

fasciotomy may permit the reestablishment of circulation through the ischemic muscle.

Although certain British surgeons[30, 36] in the Mediterranean Theater were enthusiastic advocates of fasciotomy, American surgeons in this area were much less favorably impressed by it. In the limited number of cases in which it is known to have been used the results were occasionally good, though they were poor in the majority of the wounds of the popliteal artery in which it was employed.

*Refrigeration.*—The concept of reducing the metabolism of an injured part by cooling, to make metabolic activity commensurate with such circulation as



FIG. 5.—Tense swelling of muscles of calf, without significant subcutaneous edema, 12 hours after transection of popliteal artery. Fasciotomy may aid the capillary circulation in this type of case.

is available in it, is theoretically sound.[22, 64] On the other hand, the wisdom of actual refrigeration is still open to question for any purposes except to control infection and diminish lymphatic absorption from an infected limb prior to amputation, or to permit amputation without anesthesia in an aged and debilitated subject.[50, 107, 179] Moreover, several carefully controlled studies have clearly demonstrated that after refrigeration healing progresses less satisfactorily,[107, 108] wound infection tends to progress more rapidly and to be more serious,[26, 31] and the nerves in the cooled area are liable to damage.[109]

Certain advocates of refrigeration[5-9, 44, 123, 170, 171] have proposed the use of refrigeration under combat conditions, "particularly for military emergencies

with a sudden rush of battle casualties," and have charged the failure to use it widely under such circumstances to "inaction" on the part of the military services and "official negativism" on the part of the Committee on Medical Research.[7-9] The enthusiasm of the advocates of the method, while characteristic, clearly reflects an ignorance of the therapeutic limitations imposed by military exigencies. Aside from any other consideration, the chief argument against an extensive trial of refrigeration in military vascular surgery is the utter impracticability of attempting to apply it under battle conditions.

Amputation was required in three personally observed cases in which refrigeration was used in wounds of the femoral and popliteal arteries, which is in accord with the experiences of Auster, Snyder, and Ottoway and Foote. No evidence, in fact, exists that this method has saved limbs after wounds of the major arteries, and it is to be feared, as has already been indicated, that its prolonged use can lead to damage of the tissues which it is expected to preserve.

While the application of cold to the limb is not considered wise, the application of heat directly is equally unwise. The body is warmly covered, with the exception of the limb itself, which is left uncovered and is exposed to room temperature, with the object of minimizing local tissue metabolism.

*Oxygen Therapy.*—Since lack of available oxygen is one of the factors responsible for death of tissue after vascular occlusion, oxygen inhalation has been suggested as a method of supplying the lack. An increase in the oxygen saturation of the blood is easily effected by this means when oxygenation is impaired by intrathoracic wounds or similar causes. Under normal respiratory conditions, however, an increase in the partial pressure of oxygen in the inspired air has little effect upon the oxygen content of the blood. The slight increase (15 per cent) achieved by inhalations is made possible by an increase in the amount of oxygen dissolved in the plasma. Whether or not this increase results in a sufficient increase in the oxygen gradient between the capillary blood and the rest of the tissues to affect the outcome in arterial injuries is not known. Oxygen inhalation might be desirable, but it is doubtful that the slight benefits which might be achieved compensate for the difficulties inherent in the use of the method under combat conditions. It would seem more important to devote the effort to the correction of oligemia and anemia, with the object of improving the oxygen-carrying capacity of the circulating blood.

*Posture.*—The position of an extremity in which the blood supply is embarrassed as the result of disease or injury has long been regarded of some importance. In such conditions, and particularly in acute occlusions of the main arterial channels, the blood flow to the part is impeded and must be maintained through the collateral circulation. Elevation of the extremity above the heart level accentuates the ischemia by forcing the blood flow to overcome the amount of gravity pull created by the degree of elevation above the level of the heart. For this reason it appears more rational to maintain the extremity at heart level, or preferably in a slightly dependent position, even if a moderate degree of edema appears to be the result. The experience of American surgeons has, in general, confirmed the desirability of this procedure.

Cohen,[38] on the other hand, disagrees with both the rationale and the application of this principle. He advocates elevation of the limb, basing his recommendation on the belief that this "does not empty the arterial tree and cause capillary anoxia," and that it diminishes venous pressure and increases lymph flow, with consequent prevention of edema which would compress the capillaries. The available evidence on these controversial points is not sufficiently impressive, in our opinon, to permit definitive conclusions.

Physiologic rest of the injured limb is essential, both to reduce to a minimum the nutritional needs of the tissues and to limit infection and absorption of toxic by-products. This is best achieved by immobilization in a well-padded plaster of paris encasement, the upper half of which has been removed.

## COMPLICATIONS AND SEQUELAE

As emphasized previously, this report has been concerned essentially with a consideration of acute or fresh wounds of the arteries. The local sequels of certain types of arterial or combined arterial and venous injuries, such as arterial hematoma ("pulsating hematoma"), traumatic false aneurysms, varicose aneurysms and aneurysmal varix, have been purposely omitted. In general, operative management of these lesions may be deferred for several months and is, in fact, preferable in order to permit the development of an adequate collateral circulation. Occasionally, however, certain complications arise necessitating operation, which may be urgent. These include hemorrhage, rapid expansion of the tumor, pressure upon contiguous structures such as nerves and blood vessels, infection and local pain. These complications are more liable to occur in arterial or "pulsating" hematoma and traumatic false aneurysms and are rarely observed in arteriovenous aneurysms. Occasionally excision of an arteriovenous aneurysm is indicated because of actual or impending gangrene in the periphery. Further considerations of these complications and their management may be found in a number of recent publications.[12, 32, 34, 40, 42, 43, 58, 66-68, 80, 81, 86, 98, 100, 138, 149, 190]

Other complications or sequelae include secondary hemorrhage, infection, vascular insufficiency, Volkmann's contracture, and causalgia. Secondary hemorrhage following vascular wounds was a common and greatly dreaded complication in previous wars.[2, 51, 56, 74, 82, 125, 132, 133, 154, 168, 184, 188, 189, 200-202, 208] During two years (1916–1918) of World War I, Waugh observed that among 10,000 patients with wounds involving long bones 14 per cent developed secondary hemorrhage in the first year and 9 per cent in the second year. He attributed the reduction during the latter period to "improved arrangements for adequate early excision of wounds." Tuffier,[202] in commenting upon secondary hemorrhage from arterial wounds during that period, stated that the incidence diminished "in proportion to the diminution of infected wounds." During World War II this complication has been observed relatively infrequently, as demonstrated by Freeman,[65] and by Warren. The former recorded its occurrence in only 23 (1.06 per cent) cases, 15 of which were associated with major blood vessels, among a series of 2,168 gunshot wounds. In over 9,500 casualties recorded by Warren, there were only 13 cases of secondary

hemorrhage severe enough to require operative interference or to cause death. The very low incidence and comparative insignificance of this complication in World War II is believed to be related to the lessened incidence of infection, which, in turn, is related to the performance of more adequate initial wound surgery.

Amputation after arterial wounds is done for one of two reasons, gangrene or infection. The so-called "toxic absorption," presumably the result of autolysis of muscle in the ischemic limb, for which amputation is done to relieve systemic manifestations, is probably of infectious origin in most instances. Table II shows the causes for amputations in 189 cases in this material in which amputations were done for vascular injury. The numbers, while small, suggest the relative frequency of all important complications after wounds of the arteries. When clostridial myositis and other infections are combined, it will be observed that nearly a fifth of the amputations were done for these two complications, whereas ischemia as a direct consequence of the vascular wound was the essential cause for the amputation in the remainder. In contrast with this experience, Turokets in an analysis of 49 cases of wounds of blood vessels sustained in the Finnish campaign of 1939 found that in the 12 cases requiring amputation only two were for ischemic gangrene whereas ten were for gas gangrene or infection.

Causalgia or causalgia-like conditions occasionally develop following arterial injuries and were observed during World War I, [51, 111, 112, 114] although a few reports[53, 139, 140, 191] on World War II experience have appeared in the literature. Accurate figures indicating the incidence of the condition after arterial wounds in World War II are not available. However, the complication is believed to be infrequent. This is supported by the observations of Mayfield and Ulmer, whose series of 75 cases included no patient with associated major vascular injury. In one group of 35 patients reported from a vascular center in the Zone of the Interior, causalgia was recorded only once. In another group of 77 patients, 17 cases of causalgia were observed. These figures are weighted, however, in that they include only the cases in which complications required the reference of the patients to vascular centers and do not include uncomplicated cases. It is of interest to observe in this group that the incidence of causalgia was much higher when nerve injuries were associated with the vascular injuries than when they were absent, the respective figures being 30 and 6.9 per cent. The great majority of these patients responded well to sympathetic block and sympathectomy.

After interruption of a major artery of a limb, the circulation may be so seriously impaired as to necessitate amputation of the limb; or it may be entirely adequate, so that a few weeks after the injury, there may be no detectable abnormality. Between these extremes are degrees of circulatory insufficiency which vary from symptoms brought on only after exertion to discomfort even at rest. Clinical manifestations consist of color changes, intermittent claudication, and sometimes, in the more severe cases, partial paralysis. Similar observations were made during World War I, and have been described by a num-

ber of authors,[33, 111-114, 116, 128, 144, 145, 188, 189, 201, 202] No accurate data are now available to permit statements as to the exact incidence of the condition. In one sample of 88 cases, however, vascular insufficiency severe enough to be manifested clinically was observed in 68 per cent. Two of the patients had had early sympathectomy and in 49 the operation was done late, with definite improvement in all but one. The concept of sympathectomy in these cases was developed by Leriche during the last war and this procedure apparently provided the best results that were reported in the management of this condition. Contractures involving the forearm and hand and less frequently the leg and foot constitute one of the most crippling sequels of acute ischemia consequent to arterial wounds. The conditions apparently develop as a result of severe ischemia just short of causing actual gangrene. It would appear to be essentially similar to Volkmann's ischemic contracture, which in civilian practice is usually observed in injuries associated with fractures.[2, 62, 75, 89, 164, 169] While it has not been possible to ascertain the incidence of this complication following arterial wounds, its occurrence has been relatively infrequent. In one sample of 35 cases of arterial injuries from a Vascular Center in this country there were four cases with contractures. In another sample of 77 cases from another Vascular Center there were 20 cases with contractures. While these proportions seem high it should be realized that these series of vascular cases are weighted by the fact that the Centers attract the complicated cases. The management of this condition has not been very satisfactory. Although efforts have been made to improve the circulation, including the use of sympathectomy, in general the results have been, at best, only moderately good. Other attacks upon the problem have taken the directions of orthopedic plastic operations and physiotherapy measures in the attempt to make the best use of whatever functioning muscle tissue remains.

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